# Numerical Weather Prediction

## Reprocessing of the ATSR-2 Clear-Sea Consolidated Averaged Brightness temperature dataset to skin and bulk sea surface temperatures; including a cross-comparison with ATSR-1 SSTs from 1995.

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# REPROCESSING OF THE ATSR-2 CLEAR-SEA CONSOLIDATED AVERAGE BRIGHTNESS TEMPERATURE DATASET TO SKIN AND BULK SEA SURFACE TEMPERATURES; INCLUDING A CROSS COMPARISON WITH ATSR-1 SSTS FROM 1995

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## Executive summary

Reprocessing of the ATSR-2 Clear-Sea Consolidated Averaged Brightness Temperature (CSCABT) data to high quality, high spatial-resolution sea surface temperatures (SSTs) from the second Along-Track Scanning Radiometer (ATSR-2) upon the ERS-2 satellite has been completed for the period June 1995 to December 2000. The aim is to utilise the ATSR series of instruments (ATSR1, ATSR2 and AATSR), on the European Remote Sensing (ERS) and ENVISAT satellites fully to obtain a high quality SST dataset of less than 0.3K accuracy from 1991 to at least 2006. This report describes the progress made on the reprocessing of the ATSR-2 SSTs since the ATSR-2 CSCABT dataset has been available from the Rutherford Appleton Laboratory (RAL) early in 2003. Also presented, is a cross-comparison of ATSR-1 and ATSR-2 processed SSTs from June – November 1995.

Skin SSTs and a sub-surface SST, also known as a 'bulk' SST are processed from the CSCABT dataset. This report presents results from analyses of these SSTs with other ocean SST datasets and studies the biases between different retrievals and instruments.

## 1. Methodology

## 1.1 CSCABT dataset

The ATSR-2 CSCABT data have been provided from June 1995 to December 2000 from RAL. The datasets are supplied via FTP as daily files with observations provided on a 10 arc minute spatially averaged grid. The files contain brightness temperature information, and related confidence word information.

ATSR-1 CSCABT data have also been processed for the ATSR1/2 overlap period from June 1995 to November 1995, enabling cross-comparison of the retrieved SSTs. There is an overlap of only 6 months due to problems with the performance of the cooler with the ATSR-1 instrument in the later part of its mission. The ATSR-1 instrument operated until June 1996, which was longer than the nominal mission lifetime. From early 1994 it became difficult for the cooler to maintain the detector temperatures below the optimum temperature of 95K and so to maximise the life of the cooler, temperatures were allowed to rise gradually the first largest rise being in late 1994. The detector temperatures reached 110K in early 1996. The effect of this warming is to modify the spectral

response of the 12 micron detector, which affects the calibration and adds a systematic error to the retrieved SSTs. [pers. comm. A.R.Birks].

The ATSR-1 CSCABT data provided for 1995 has no 3.7μm brightness temperature information available as the channel failed in May 1992. This means that it is not possible to do a cross-comparison between dual-view 3-channel retrievals (hereafter D3), where SSTs are retrieved from a combination of 3 brightness temperature channels: 3.7μm, 11μm and 12μm. The D3 retrieval method is only possible during the night when there is no possibility of contamination of the 3.7μm channel from visible light. Therefore, section 3. on the cross comparison between ATSR-1 and ATSR-2 retrieved SSTs only contains comparisons from the dual-view 2-channel retrievals (hereafter D2), using 11μm and 12μm brightness temperatures only. It must be noted that as the 3.7μm channel is unavailable from the ATSR-1 instrument, this may have impacted the quality of the cloud-clearing routines performed at RAL, and thus we may observe more cloud contamination in the ATSR-1 data.

Note the confidence word in the ATSR-1 CSCABT products was flagged as 'poor' for all observations in the comparison period. Processing of ATSR-1 CSCABT data continued regardless as no explanation on why these flags were set could be obtained. Ignoring these 'poor' flags enabled comparisons to be made.

## 1.2 SST processing scheme

A processing scheme at the Met Office processed the CSCABT brightness temperatures a month at a time, and is described within figure 1. The processor firstly retrieves a skin SST (D2 or D3) from the 10arc minute brightness temperatures. For the ATSR-2 CSCABT data the skin SSTs are calculated by using the Merchant July 2000 [1,2] skin retrieval coefficients, which are derived from linear regression from brightness temperatures simulated using a radiative transfer model.

These skin SSTs are then processed to a bulk SST, which is the temperature of the ocean at around 1metre in depth. This is done by using the Fairall model [3] and is necessary because the satellite observes a radiative skin temperature which is always cooler than the sub-skin by more than 0.1K. For obtaining SST for climate purposes we require the bulk temperature which provides a more comparable measurement when looking at other climate datasets, and is more representative of the overall heat capacity of the ocean. The value of lambda used within the skin effect model is 4.5 [4].

At night the sub-skin SST is representative of the bulk SST at around ~1metre in depth. However, during the day the sub-skin SST can become warmer than the bulk SST by several Kelvins, especially in cases of strong insolation and low wind speed where thermal stratification results. These locations are typically in low-latitudes, but can reach mid-latitudes if local atmospheric conditions are favourable. These diurnal warming effects are modelled at the Met Office, using the Kantha-Clayson [5] model to try to predict occurrences of warmings within the 10arc minute resolution cells, with NWP fluxes and wind observations needed for inclusion in the models. Such predictions are flagged in the observation record and affected observations are not included in further analyses.

The processor produces an output bulk product, which consists of an ascii file for each day containing all the brightness temperatures, skin SSTs, skin to bulk deltaTs, and confidence information (including a thermocline flag).

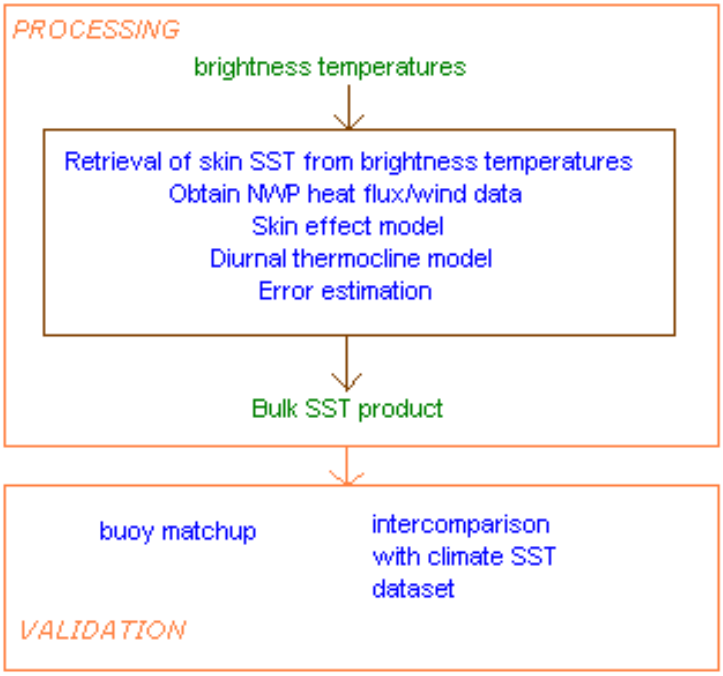



Figure 1. ATSR-1/2 processing scheme.

Also described in [4] is the value of an offset designed to be added to the bulk SSTs which is due to the associated error from the NWP model fields used in the skin effect model. This value of the 'flux offset' is set at -0.04K, and is specified within the header of the output bulk product, and it is not included within the bulk SSTs of the main data leaving the user to add the offset to the data if desired.

## 1.3 Validation against buoy SSTs and HadISST1

ATSR-2 bulk SSTs for 1995 to 2000 and ATSR-1 bulk SSTs for June to November 1995 have been compared against both moored and drifting buoy SST measurements, representative of a bulk SST at around 1 metre in depth. The buoy SST measurements have been extracted from the Global Telecommunications System. Comparison of the ATSR SSTs against buoy SSTs, the buoy matchup processing, takes place on a months data at a time. Eventually a large buoy-matchup database is created from a collection of 79 different variables detailing the buoy observations, AATSR observations, and atmospheric and sea surface conditions.

The matching up of the two observation types involves choosing buoy observations which are located within the 10arc minute resolution grid box of the ATSR observation. The time difference between the two data types must be within ±3 hours. In the event that 2 buoy SSTs are matched up to the same ATSR observation, the buoy observations closest in time to the AATSR observation will be chosen. Efforts to screen out residual cloud contamination in the observations are made by checking for gross differences between the dual and nadir retrieved SSTs, between D2 and D3 retrievals (when D3 are available) and also an extra check for ice. These checks are performed within the Met Office (A)ATSR skin and bulk processing scheme, and the information assigned within a quality control (QC) word. Statistics are performed on these matchup data, however efforts should be made to better represent a consistent global distribution in future analyses.

The Hadley Centre Sea Ice and Sea Surface Temperature dataset (HadISST), a global SST climate dataset provided by the Hadley Centre [6], is compared on a monthly basis to the ATSR bulk SSTs. The HadISST1 analyses are a globally complete 1° spatial resolution sea-ice and SST analysis field, compiled from buoy and ship SSTs plus SSTs derived from the Advanced Very High Resolution Radiometer (AVHRR) on the National Oceanic and Atmospheric Administration (NOAA) satellites.

ATSR-1 bulk SSTs have been compared against HadISST1 on a monthly basis from June – November 1995, whilst the ATSR-2 bulk SSTs have been compared to HadISST1 from June 1995 to December 2000. There is a gap in ATSR-2 data availability from January to June 1996 when the ATSR-2 instrument experienced scan mirror problems.

## 2. ATSR-2 Sea Surface Temperatures

### 2.1 Mean global ATSR-2 SSTs

ATSR-2 skin and bulk SSTs have been meaned onto a one-degree grid, and example global map for January 1997 is shown in figure 2.

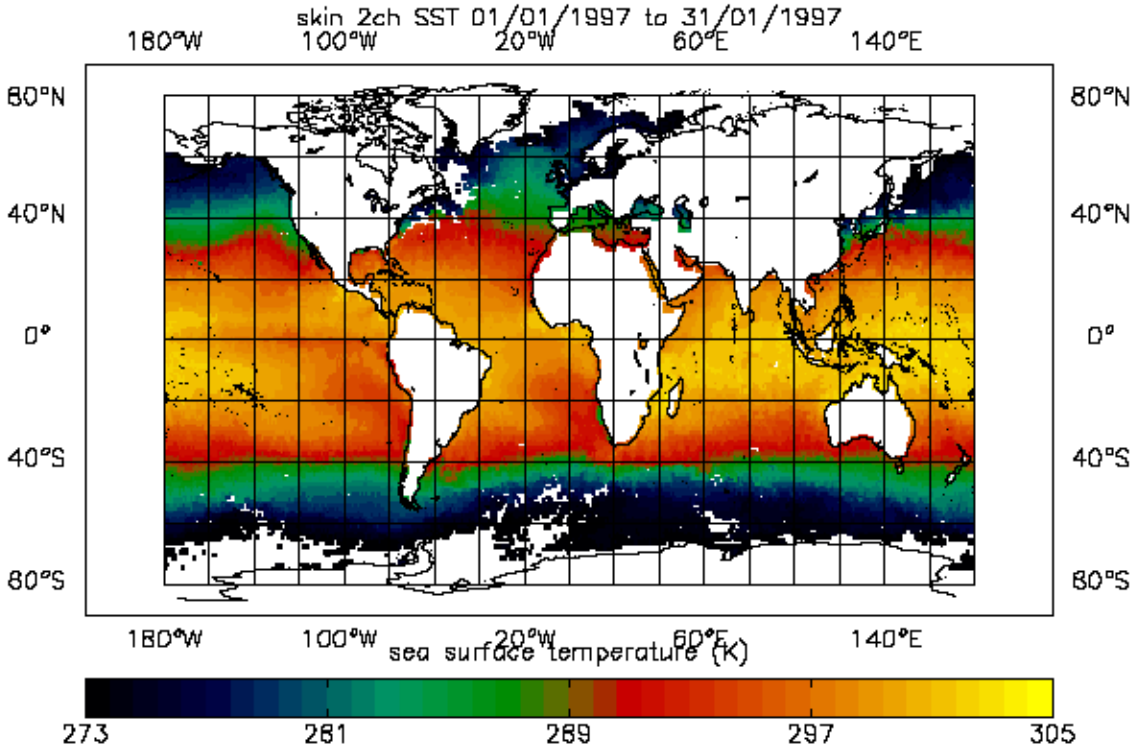



Figure 2 ATSR-2 D2 skin SST for January 1997

Biases in SST retrievals are caused by two factors: retrieval errors which are state dependent and vary with atmospheric state; and also a mean global offset which varies according to whether a D2 skin retrieval or D3 skin retrieval has been performed. The results in this report are presented where the ATSR-2 skin SSTs have been corrected with a mean global offset (the second factor), however the retrieval errors (first factor) have not been corrected.

It is possible to attempt to correct for retrieval errors. The retrieval error varies with latitude, longitude and season. A correction could be applied to the retrievals to reduce the state dependent error. The skin to bulk deltaT would still be assumed to be the same in these instances

Figure 3 shows the ATSR-2 D2 minus D3 skin SST global difference map for June 1995. There is a large latitude dependent variation in the differences. However, the corrections which could be applied to the skin SSTs are only applied to D2 retrievals, as these are where the largest errors occur. D3 retrievals are known to be less susceptible to retrieval errors due to the additional brightness temperature channel available to calculate the SST. Whilst using (A)ATSR SSTs in climate studies, efforts should always be made to use the 3-channel retrievals over the 2-channel retrievals.

Additionally as these are always night-time observations they are less susceptible to diurnal warming effects.

The global offset has previously been calculated from CSCABT data processed from January to August 1998. Values are below in table 1. It was done by compiling a matchup dataset between ATSR-2 observations and buoy SSTs from January to August 1998. The buoy SSTs were corrected to a skin SST using the Fairall model and then compared with the ATSR-2 skin SSTs for D2 and D3 night separately. Then the mean differences between the satellite skin and buoy SSTs are used for the offsets. It can be assumed that the D2 day-time offset can be assigned to the value of the D2 night-time value, as calculating the D2 day-time separately should be avoided to eradicate the effects of diurnal warming as much as possible. To correct for the errors induced in the radiative transfer modelling, these offsets should be added to the ATSR-2 skin SSTs. These are preliminary results which were used in the main processing of the ATSR-2 1995-2000 data, however, revised offsets are presented in section 3.4.

| | **Skin D2 night** | **Skin D3 night** | **Skin D2 day** |
|---|---|---|---|
| **Mean Offset (K)** | 0.05 | -0.11 | 0.05 |

Table 1. Global offsets to apply to ATSR-2 data to correct the mean global offset, calculated using ATSR-2 data matched with buoy SST from January to August 1998.

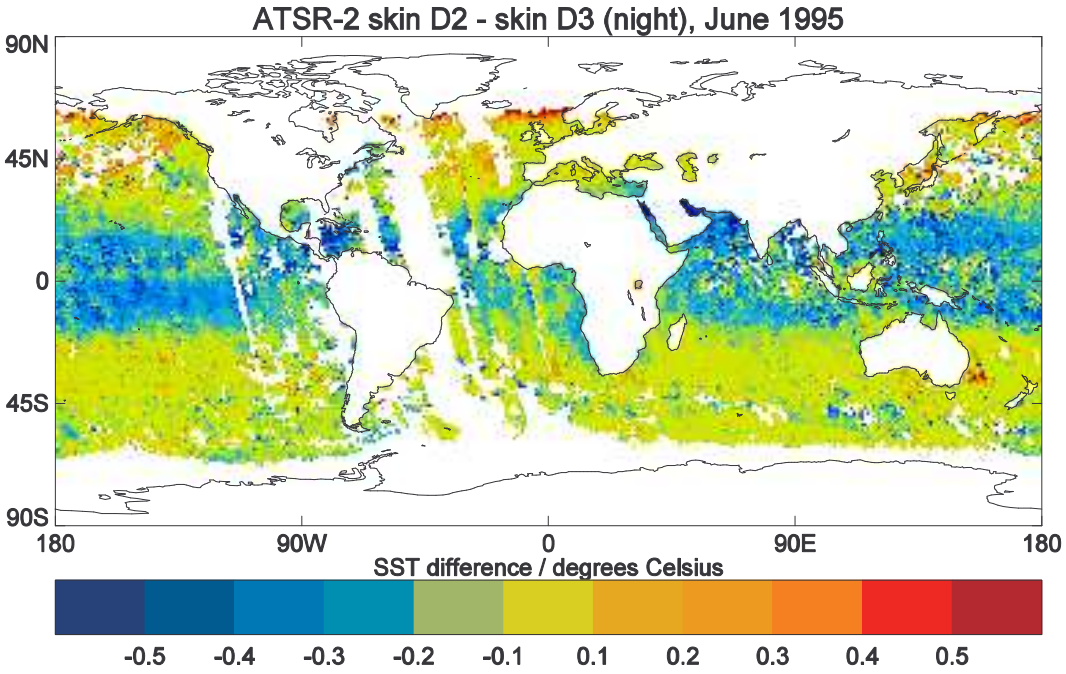



Figure 3 ATSR-2 D2 minus D3 skin SST global difference map for June 1995

## 2.2 Comparisons of ATSR-2 SSTs against buoy SSTs

Figure 4 shows the timeseries of ATSR-2 skin and bulk SSTs minus buoy SSTs for satellite-buoy matchups from May 1995 to December 2000. Note that a gap in the data occurs in the first half of 1996 due to scan-mirrors problems with the satellite. Over the 5 year time period the retrievals are within around ±0.3K. A few anomalies are noted mainly where the buoy SST is warmer than the satellite SST, but generally temperatures are comparable. The ATSR-2 bulk SST is warmer than the skin SST when compared to buoys which is expected. Table 3 shows differences between skin and bulk SSTs of ~0.12K when compared to buoy SSTs, where the bulk SSTs are warmer than the skin SSTs. For example, the ATSR-2 bulk SST (night-time) minus buoy SST is 0.0K at, and the ATSR-2 skin SST (night-time) minus buoy SST is -0.07K.

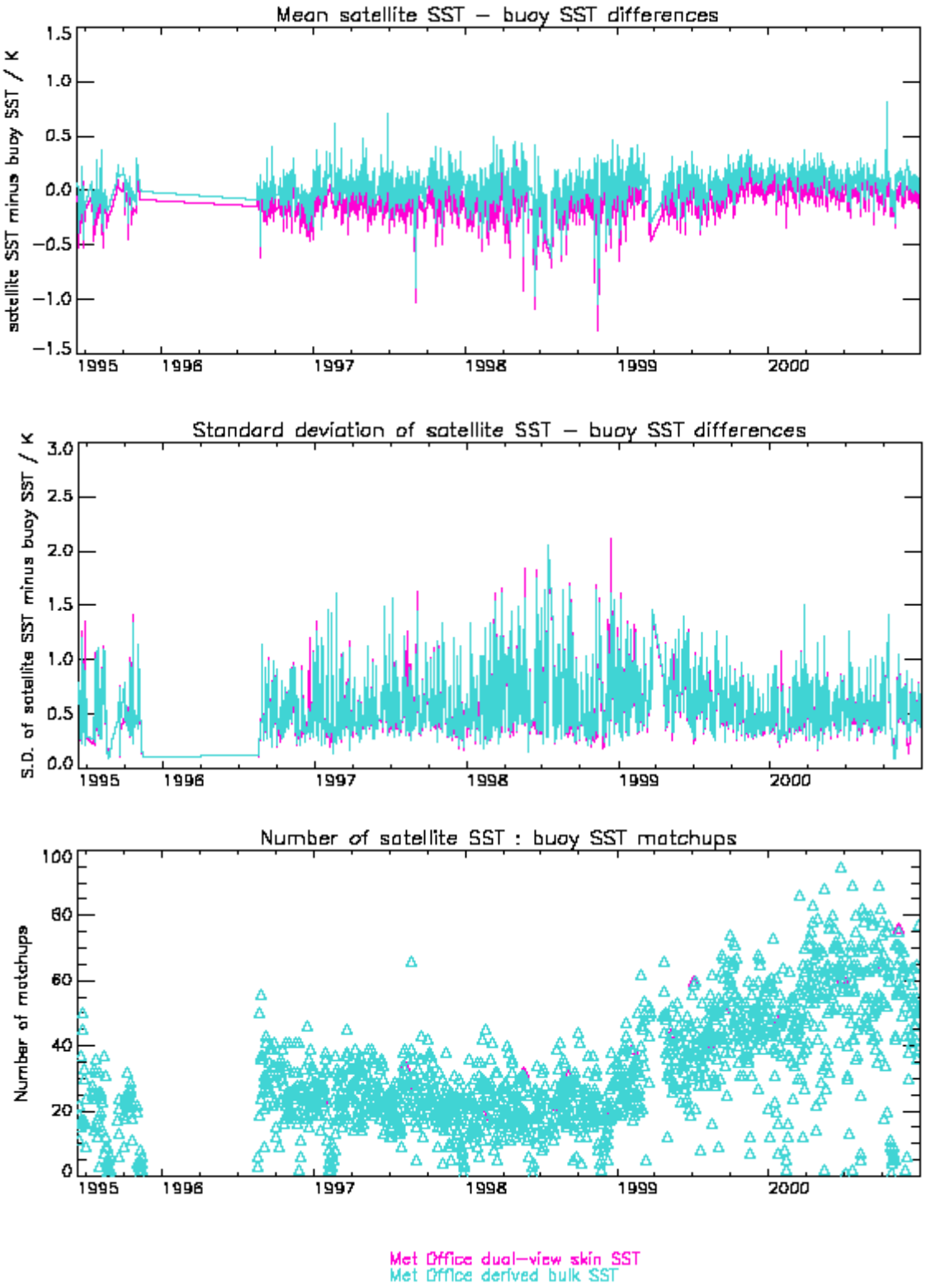



Figure 4 Timeseries of ATSR-2 minus buoy SSTs from May 1995 to December 2000.

| SST type | Subset | Mean (ATSR–buoy SST), K | Standard deviation (K) | Number matchups |
|---|---|---|---|---|
| Skin | Day + Night | -0.08 | 0.65 | 53843 |
| Skin | Day | -0.09 | 0.72 | 27169 |
| Skin | Night | -0.07 | 0.59 | 26678 |
| Bulk | Day + Night | 0.04 | 0.63 | 49707 |
| Bulk | Day | 0.09 | 0.69 | 25071 |
| Bulk | Night | 0.00 | 0.57 | 24634 |

Table 2. Statistics of ATSR-2 minus buoy SSTs from May 1995 to December 2000.

## 2.3 Comparisons of ATSR-2 SSTs with HadISST1

ATSR-2 bulk SSTs (D2 day, D3 night) have been compared against the HadISST1 analyses. Figures 5a and 5b show example difference plots for January 1997 and May 1997. Generally the ATSR-2 bulk SSTs compare well with the HadISST1 analyses, but with some noteable features. Polewards of South Africa, there is a line of differences in both plots where ATSR-2 is warmer than HadISST to the north and cooler to the south, which may be due to a misplacement of a sharp gradient of SST in HadISST. Also large differences in both directions are seen around Patagonia. The plot for May 1997, shows that ATSR-2 is upto 0.4K warmer than HadISST in the Gulf Stream region; perhaps HadISST is not locating these warmer SSTs in this region of strong SST gradients. To the West of Africa in the May 1997 plot, ATSR-2 can be seen to be cooler than HadISST in this region of typical marine stratiform cloud formation. This type of cloud is notorious difficult to detect in the cloud detection routines (performed at RAL for this dataset), so the anomaly may be due to some residual cloud contamination.

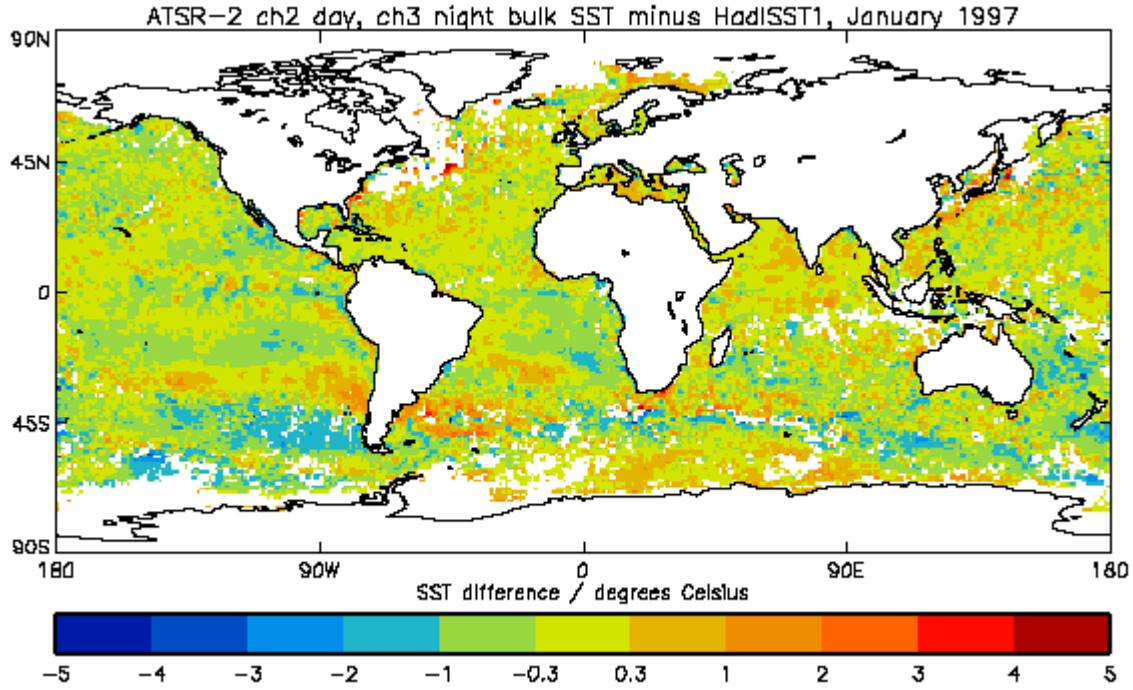



Figure 5a ATSR-2 bulk SST (D2 day, D3 night combined) minus HadISST1 for January 1997

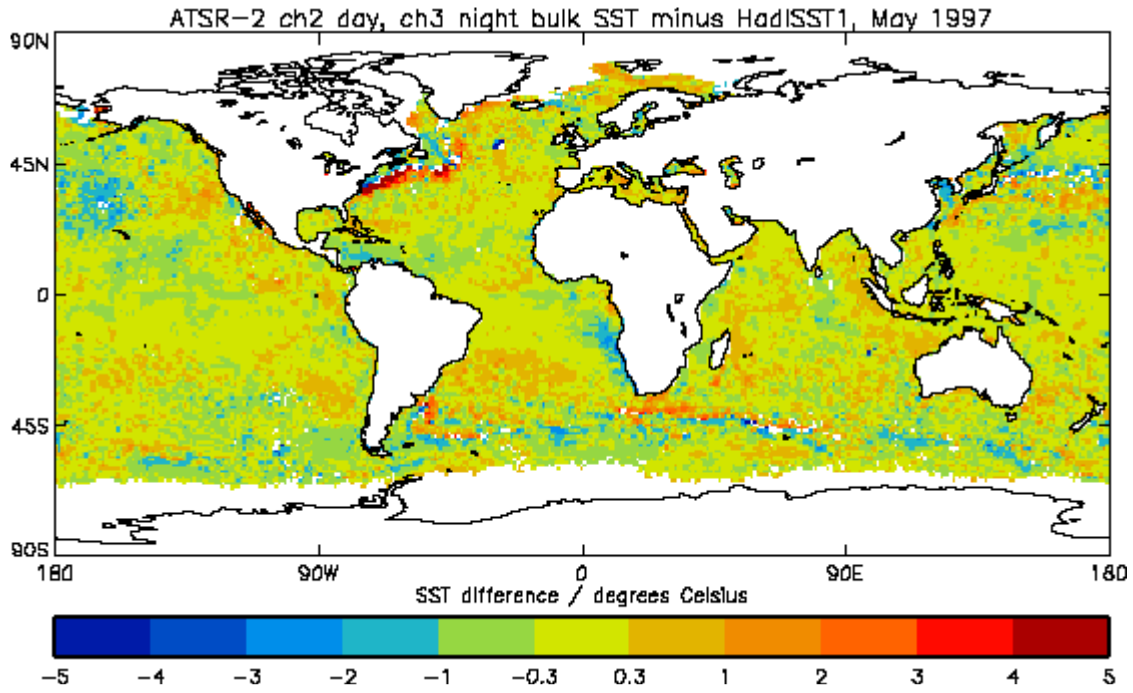



Figure 5b ATSR-2 bulk SST (D2 day, D3 night combined) minus HadISST for May 1997

| | Global mean ATSR-2 Bulk SST (D3, night) minus HadISST1 (K) | | |
|---|---|---|---|
| | **Mean** | **Standard deviation** | **Number of obs** |
| **ATSR-2** | -0.11 | 0.68 | 1659861 |

Table 3. Statistics of ATSR-2 minus HadISST1 for May 1995 to December 2000.

Overall, from May 1995 to December 2000, the table 3 results of bulk ATSR-2 SSTs differences with HadISST, show the bulk SSTs to be slightly cooler than HadISST.

## 2.4 Timeseries of ATSR-2 minus 61to90 climatology

Figure 6 shows the timeseries of ATSR-2 bulk SST (D3 night) minus a 61to90 climatology. The climatology is supplied by the Hadley Centre. The bulk SSTs have been corrected with the global correction listed in section 2.1. The anomalies seem to follow a seasonal variation, and the global SSTs become much warmer than the climatology around the time of the 1998 El-Nino.

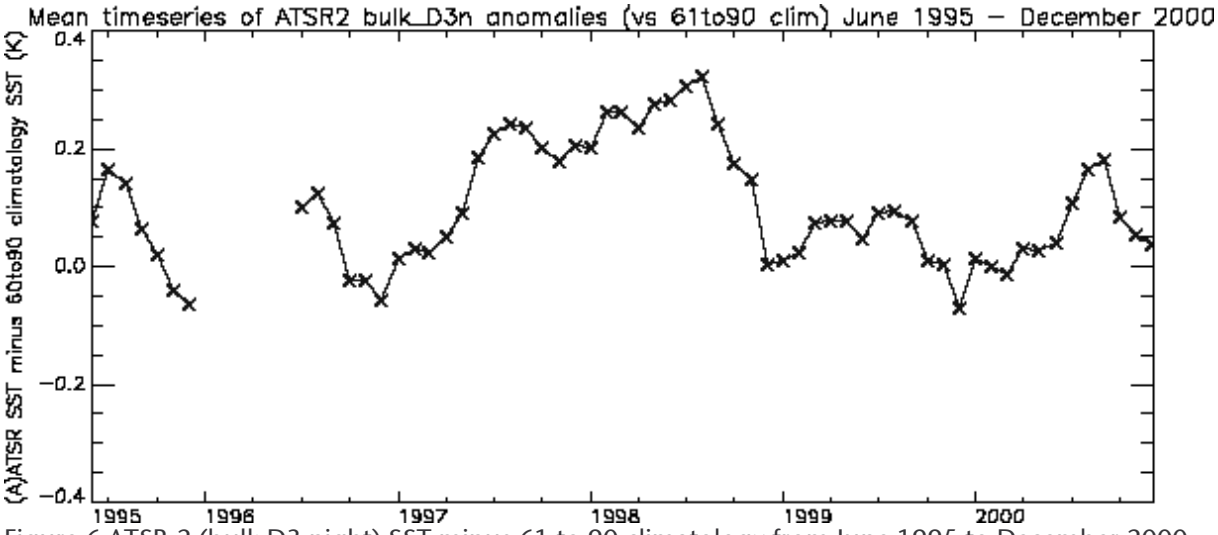


Figure 6 ATSR-2 (bulk D3 night) SST minus 61 to 90 climatology from June 1995 to December 2000

# 3. ATSR-1 cross comparison with ATSR-2

## 3.1 Mean SST comparisons

The mean D2 global skin and bulk SSTs, for night-time only results, from June – November 1995, for both ATSR-1 and ATSR-2, are presented in table 4 below. The mean offsets, given in Table 1 have corrected the ATSR-2 skin and bulk SSTs before the analysis was done, however the flux error offset is not added to the satellite SSTs. No offsets are applied to the ATSR-1 data.

| **Mean global SSTs (K)** | **Night-time D2 Skin SST** | **Night-time D2 Bulk SST** |
|---|---|---|
| **ATSR-1** | 291.56 | 291.72 |
| ATSR-2 | 292.07 | 292.22 |

Table 4. Mean global ATSR-1 and ATSR-2 SSTs from June to November 1995.

The mean global ATSR-2 night-time D2 skin SST is 0.51K warmer than the ATSR-2 mean SST from June to November 1995. The ATSR-2 global mean D2 bulk SST is 0.5K warmer than the ATSR-1 mean SST over the same period which is a significant difference. Figure 7 shows how the global mean skin and bulk SSTs vary throughout the 6 month period. It illustrates again how the global ATSR-1 SSTs are up to 0.5K cooler than for ATSR-2. We will consider this characterisation in further sections, but perhaps the lack of the 3.7μm channel in the RAL cloud-clearing has allowed residual cloud-contamination to cool the overall ATSR-1 global mean SST. Without the 3.7μm channel typical areas where cloud has not been detected would be marine stratiform cloud which often occurs to the West of large continents, which can be seen in figures 9a to 9c.

Additionally, figure 7 shows the ATSR-1 and ATSR-2 mean skin and bulk SSTs for a selected area within the +40 and -40 latitude range, thus excluding satellite observations at high latitudes. The ATSR-1 and ATSR-2 skin SSTs thoughout the 6 month comparison period are much closer. The ATSR-1 mean skin SST for the period is 296.97K and the ATSR-2 mean skin SST is 297.11K, thus the ATSR-2 is warmer than ATSR-1 by only 0.14K.

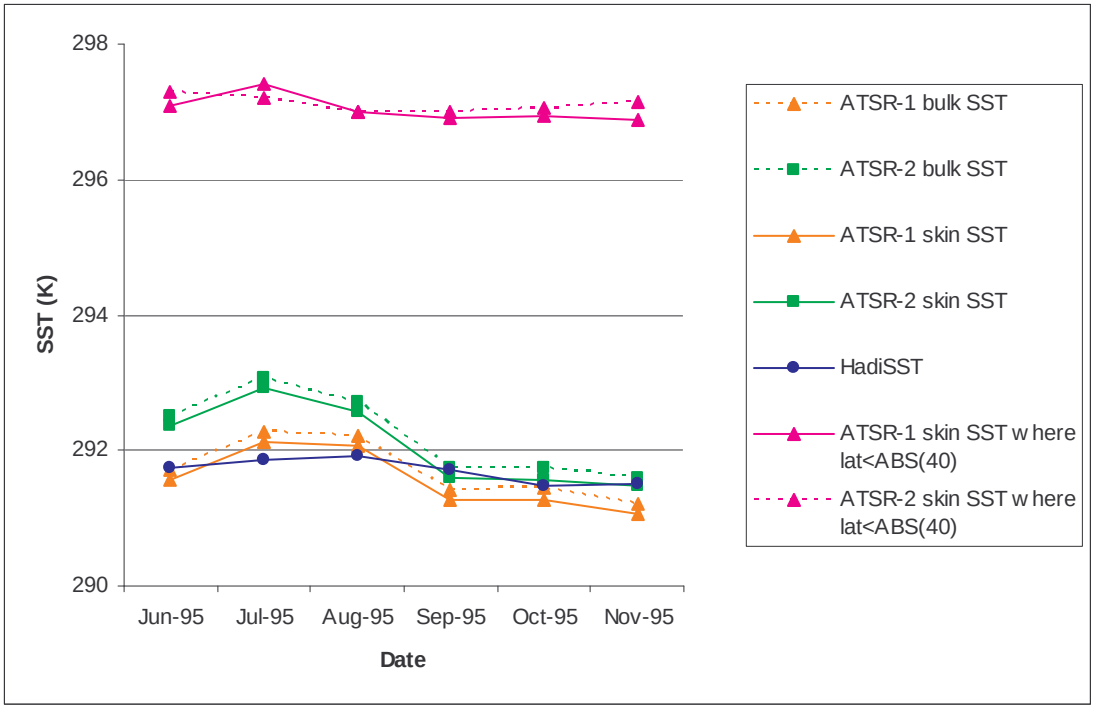



Figure 7. Timeseries of monthly mean ATSR-1 and ATSR-2 night-time D2 skin and bulk SSTs from June to November 1995.

Figure 8 shows the ATSR-1 D2 skin SSTs meaned into 1degree cells for October 1995. Figure 9a shows the difference between these SSTs and the ATSR-2 D2 skin SSTs for the same month. As D3 retrievals are not possible with the ATSR-1 CSCABT in 1995, no analysis of D2-D3 differences is possible for ATSR-1 as presented in section 2.1. The plot displayed as figure 9a illustrates that the largest differences between ATSR-1 and ATSR-2 D2 skin SSTs (night-only) are at latitudes greater than ±40°, where the overall signal is that ATSR-2 is warmer. In the tropics the SSTs between the 2 instruments are much more comparable, except in certain areas such as West Africa where the mean ATSR-2 SSTS are upto 0.5K warmer than the ATSR-1 mean SSTs. Undetected marine statiform cloud, common in this region could be contaminating the ATSR-1 SST signal in this region.

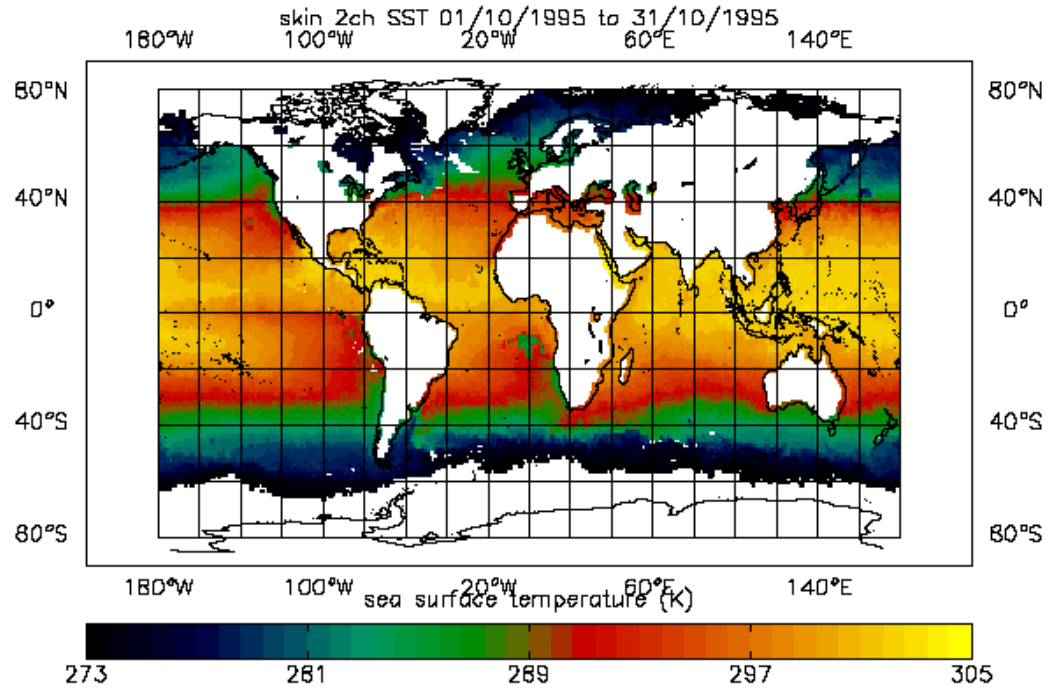



Figure 8 Dual-view 2-channel skin SST map for ATSR-1 October 1995

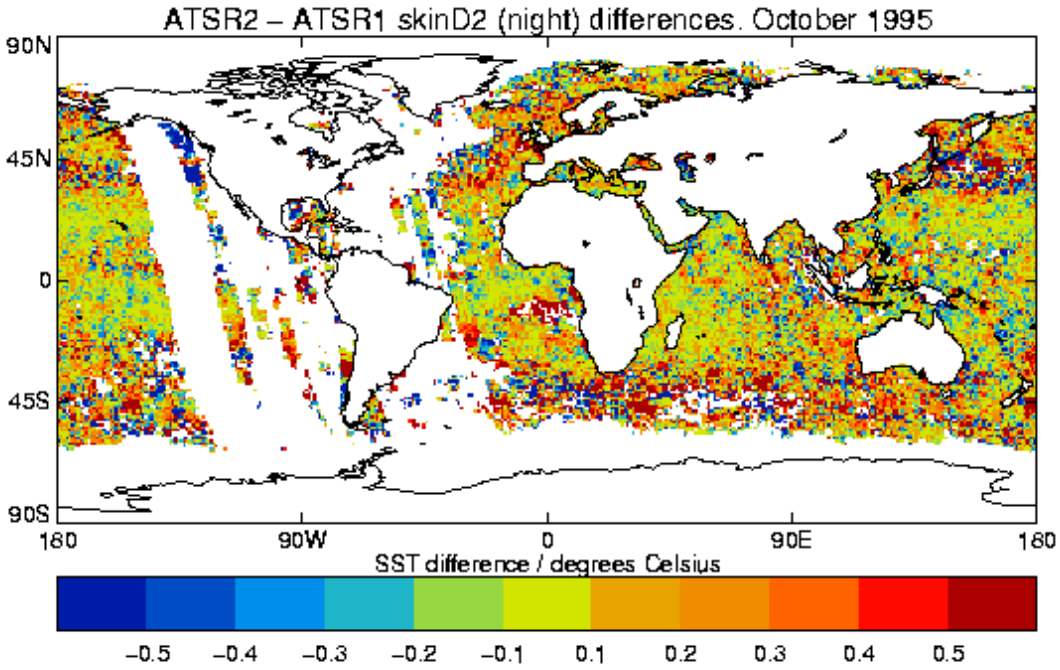



Figure 9a Dual-view ATSR-2 minus ATSR-1 skin SST difference map for ATSR-2 October 1995

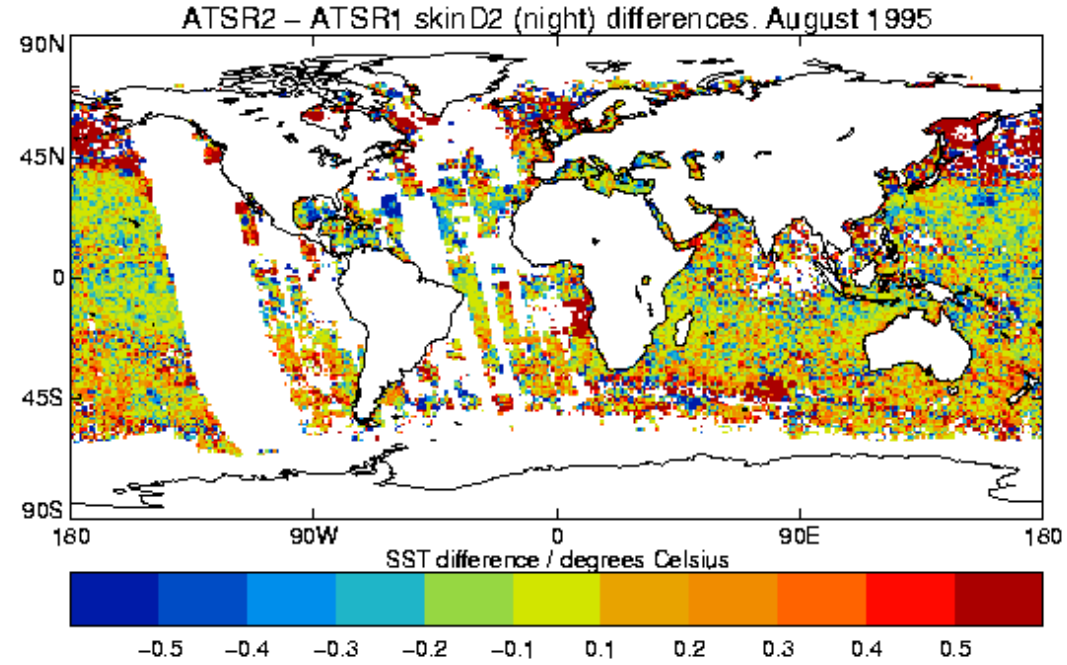



Figure 9b Dual-view ATSR-2 minus ATSR-1 skin SST difference map for ATSR-2 August 1995

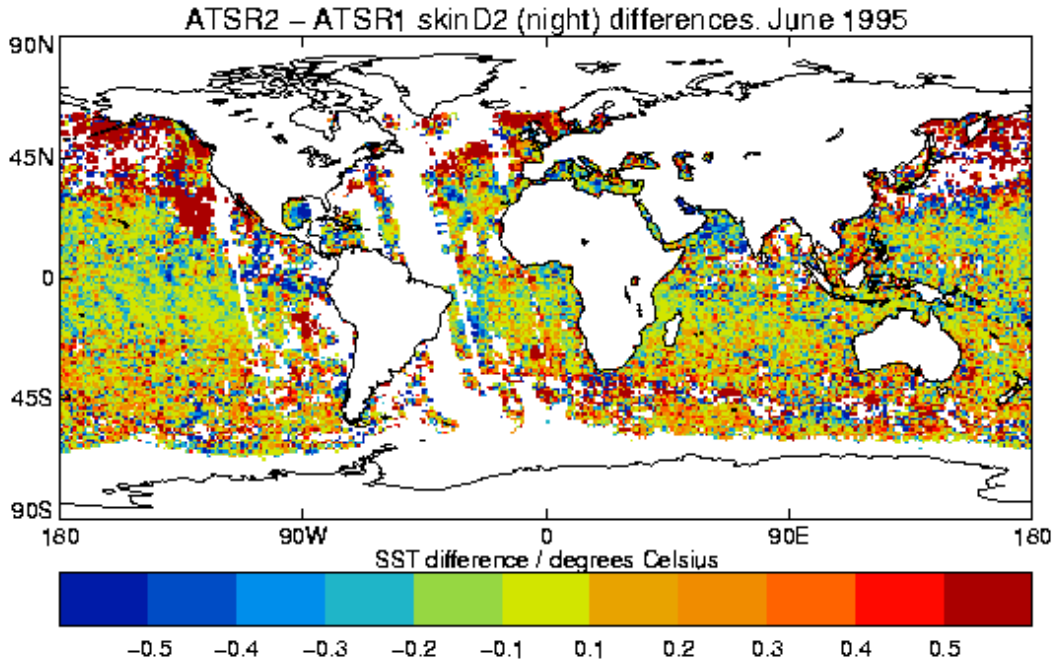



Figure 9c Dual-view ATSR-2 minus ATSR-1 skin SST difference map for ATSR-2 June 1995

Figures 9b and 9c show similar plots as 9a, but for the months June and August 1995. Again, the largest difference between the skin SSTs for the two instruments are at the poles, especially in the northern hemisphere in these examples.

## 3.2 Comparisons with buoy SSTs

Figure 10 shows the coverage of buoy SSTs matched with ATSR observations from 1st June 1995 to 15 November 1995. A good spread of matchups has been obtained for the period, with a few in the Southern Ocean and mid-Atlantic as expected, but the dataset also includes data from the Pacific TAO buoys. There are some missing data period of in situ buoy SST data: July 1-15th, September 1-15 and

November 16-30th 1995. However, ~2000 matchups were made for ATSR-1 and ATSR-2 which is a good number to evaluate in the 6 month period.

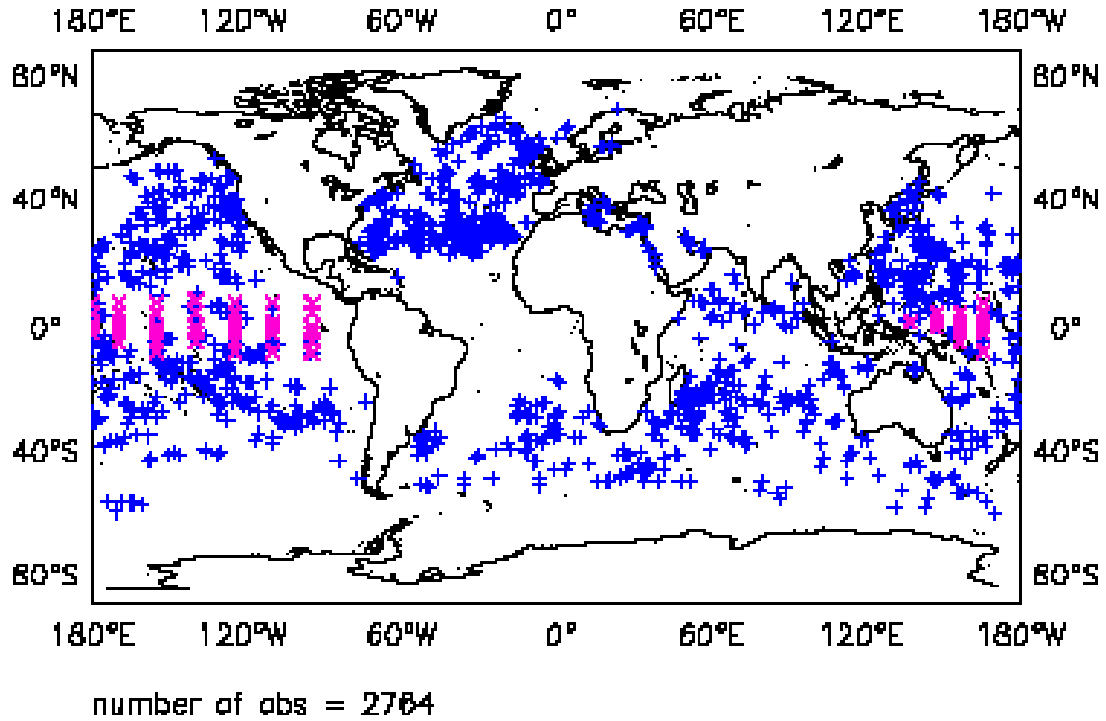



Figure 10 Locations of buoy SSTs matched with ATSR SSTs from 1st June 1995 to 15th November 1995. (pink = moored buoys, blue = drifting buoys).

Table 5 shows statistics (after using 3 sigma standard deviation test) from these analyses of buoy SSTs matched up with ATSR1/2 skin and bulk SSTs in the same period. The ATSR-2 statistics are presented without the offsets described in section 2.1 to keep consistent with the ATSR-1 results. The results show that both ATSR-1 and ATSR-2 SSTs are slightly cooler than the buoy SSTs. The bulk SSTs at night are within 0.02K and 0.05K from the mean buoy SST for ATSR-1 and ATSR-2 respectively. However, as no 3-channel retrievals are available for ATSR-1 data the ATSR-1 results will be using mainly 2-channel retrievals at night, whilst ATSR-2 will use 3-channel retrievals. The day-time results are also similar for both the ATSR-1 and ATSR-2 statistics, where the satellite skin SST – buoy bias is -0.22K and -0.27K respectively.

| SST type | Subset | Mean (ATSR–buoy SST), K | Standard deviation (K) | Number matchups |
|---|---|---|---|---|
| **ATSR-1** | | | | |
| **Skin** | **Day + Night** | -0.27 | 0.63 | 2662 |
| **Skin** | **Day** | -0.22 | 0.51 | 1122 |
| **Skin** | **Night** | -0.30 | 0.76 | 1544 |
| **Bulk** | **Day + Night** | -0.10 | 0.62 | 2632 |
| **Bulk** | **Day** | -0.07 | 0.51 | 1107 |
| **Bulk** | **Night** | -0.02 | 0.73 | 1526 |
| **ATSR-2** | | | | |
| **Skin** | **Day + Night** | -0.20 | 0.57 | 1757 |
| **Skin** | **Day** | -0.27 | 0.53 | 936 |
| **Skin** | **Night** | -0.12 | 0.62 | 832 |
| **Bulk** | **Day + Night** | -0.07 | 0.54 | 1644 |
| **Bulk** | **Day** | -0.09 | 0.49 | 884 |
| **Bulk** | **Night** | -0.05 | 0.61 | 761 |

Table 5 Statistics of satellite minus buoy SST differences for ATSR-1 and ATSR-2 from 1st June 1995 to 15th November 1995.

Figure 11a shows the daily mean ATSR-1 SST – buoy SST timeseries, whilst figure 11b shows the daily mean ATSR-2 SST – buoy SST timeseries. The figures show that ATSR-1 and ATSR-2 bulk SSTs both have the 0.3K absolute accuracy required for the (A)ATSR instruments when compared with buoys. The mean night-time ATSR-1 skin SST minus buoy SST is -0.3K, whereas for ATSR-2 the value is -0.12K, thus the ATSR-2 skin SSTs are slightly closer to the buoy SSTs than for ATSR-1. However the bulk SST differences are very close for the two instruments, where the mean ATSR-1 night-time skin SST minus buoy SST difference is -0.02K and the corresponding value for ATSR-2 is -0.05K. The higher standard deviations for ATSR-1 night-time statistics arise from poorer cloud detection at night due to the lack of 3.7μm channel.

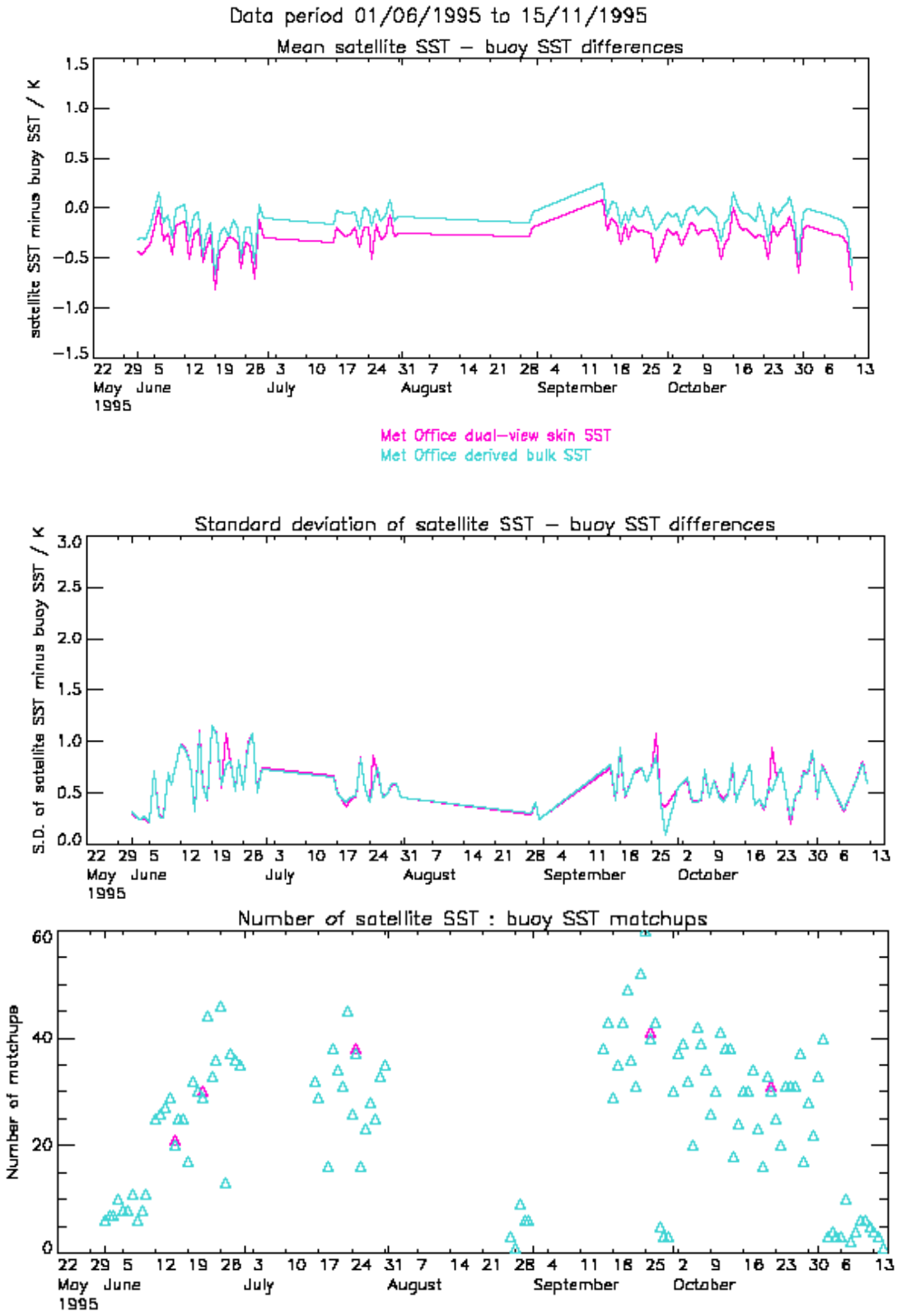



Figure 11a Daily mean timeseries of ATSR-1 skin and bulk SST minus buoy SST, including timeseries of standard deviation and number of matchups for 1st June 1995 to 15th November 1995.

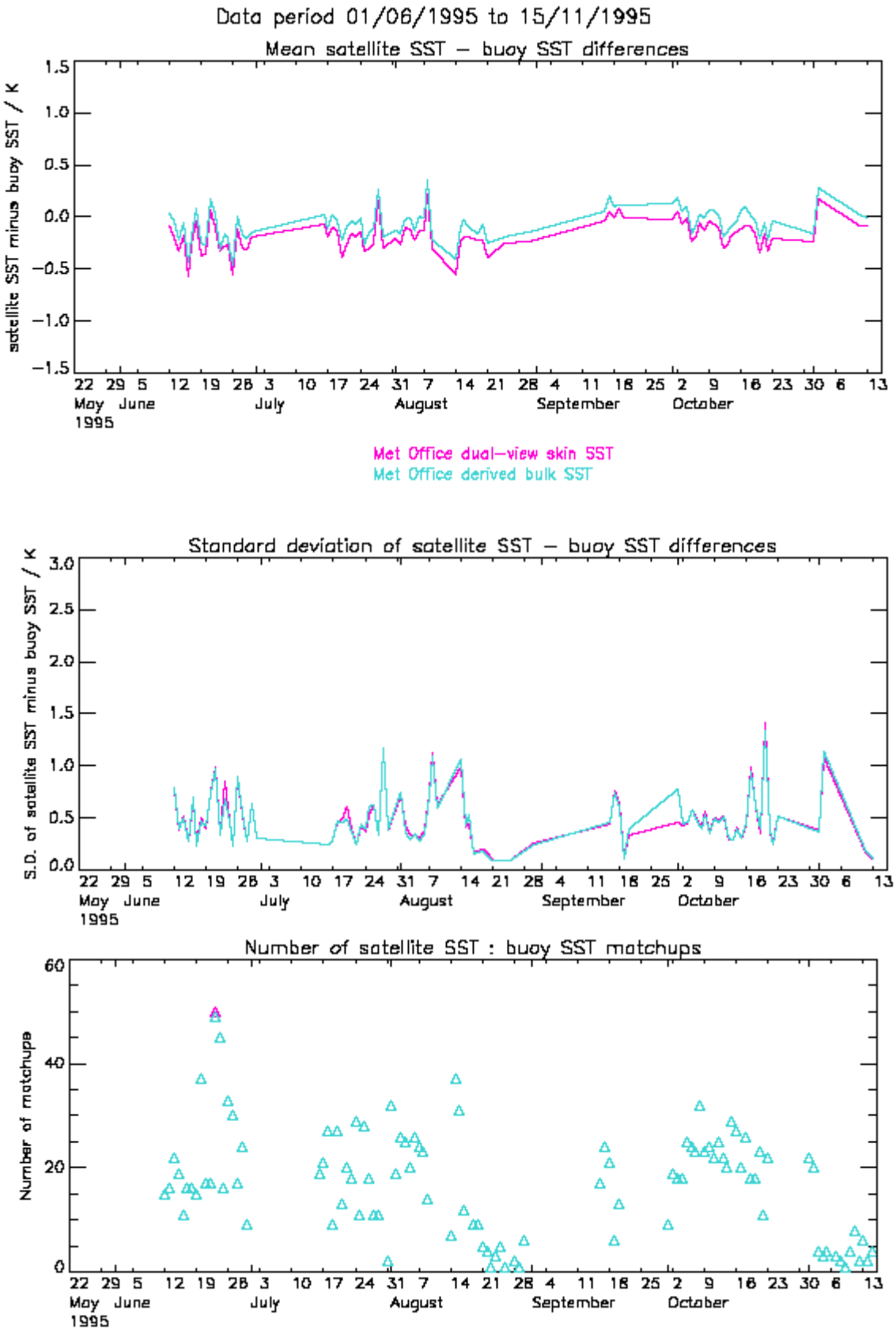



Figure 11b Daily mean timeseries of ATSR-2 skin and bulk SST minus buoy SST, including timeseries of standard deviation and number of matchups for 1st June 1995 to 15th November 1995.

Figure 12 shows histograms of ATSR-1 and ATSR-2 bulk SSTs minus buoy SSTs for global matchups and high-latitude (>±50°) matchups. Both instruments have slight indications of a cool tail (indicating

residual cloud contamination) in the global plots, but it is more pronounced in the ATSR-1 plots. At high latitudes, the cold signal in the ATSR-1 plot is much more significant than for ATSR-2 suggesting that the lack of 3.7 channel in the ATSR-1 cloud-clearing is causing residual cloud contamination in the satellite SST retrievals at high latitudes.

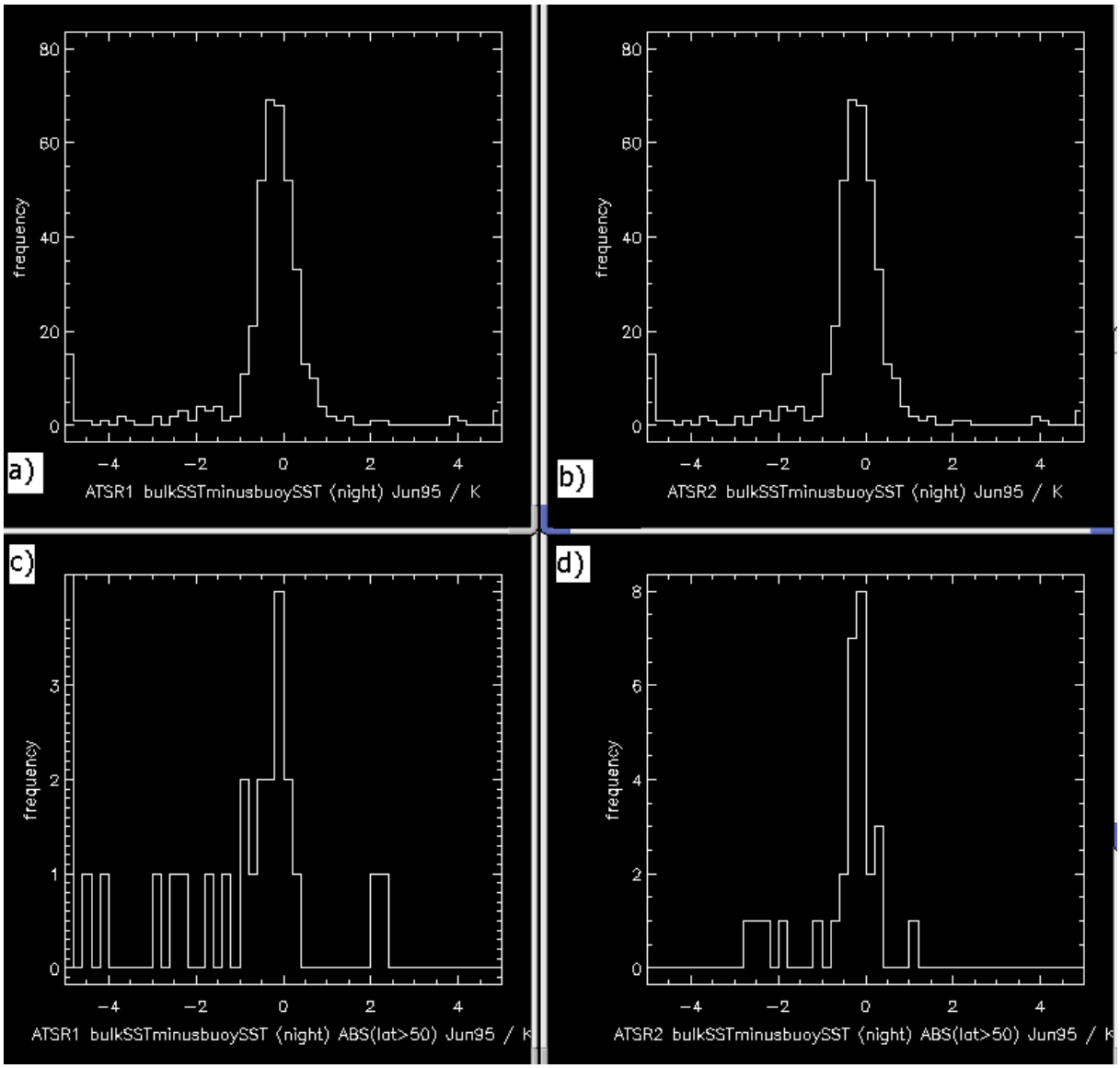



Figure 12 Histograms of ATSR-1 and ATSR-2 minus buoy SST for a) Global ATSR-1, b) Global ATSR-2, c) High-latitude (latitude greater than ±50°) ATSR-1, d) High-latitude ATSR-2

3.3 Comparisons with HadISST1

ATSR-1 and ATSR-2 D2 night-time skin and bulk SSTs have been compared with HadISST1 SSTs. Table 6 below shows the mean differences for the period June to November 1995. The skin and bulk SSTs used within the analysis have been corrected with a global offset, but not the flux error offset. The results show that the ATSR-2 bulk SSTs are warmer than the ATSR-1 SSTs by 0.1K compared to HadISST, where the ATSR-2 bulk SSTs are closer to HadISST than the ATSR-1 SSTs.

| Global stats (K) | Bulk SST (D2 night) – HadISST | | |
|---|---|---|---|
| | mean | Standard deviation | Number of obs |
| **ATSR-1** | -0.23 | 0.7 | 177008 |
| **ATSR-2** | -0.13 | 0.7 | 192678 |

Table 6. Mean ATSR-1 and ATSR-2 bulk SST (channel 2 night-time only) minus HadISST1 for June – November 1995

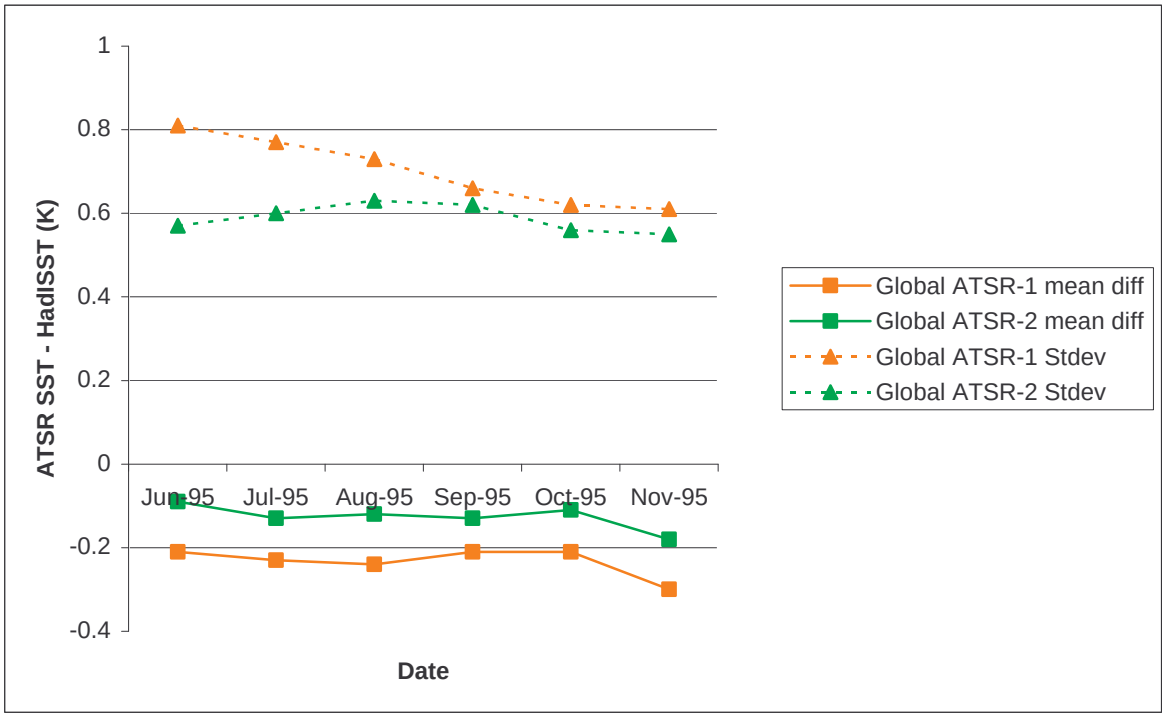



Figure 13a. Global monthly means of ATSR-1 and ATSR-2 bulk SSTs (night) minus HadISST from June 1995 to November 1995.

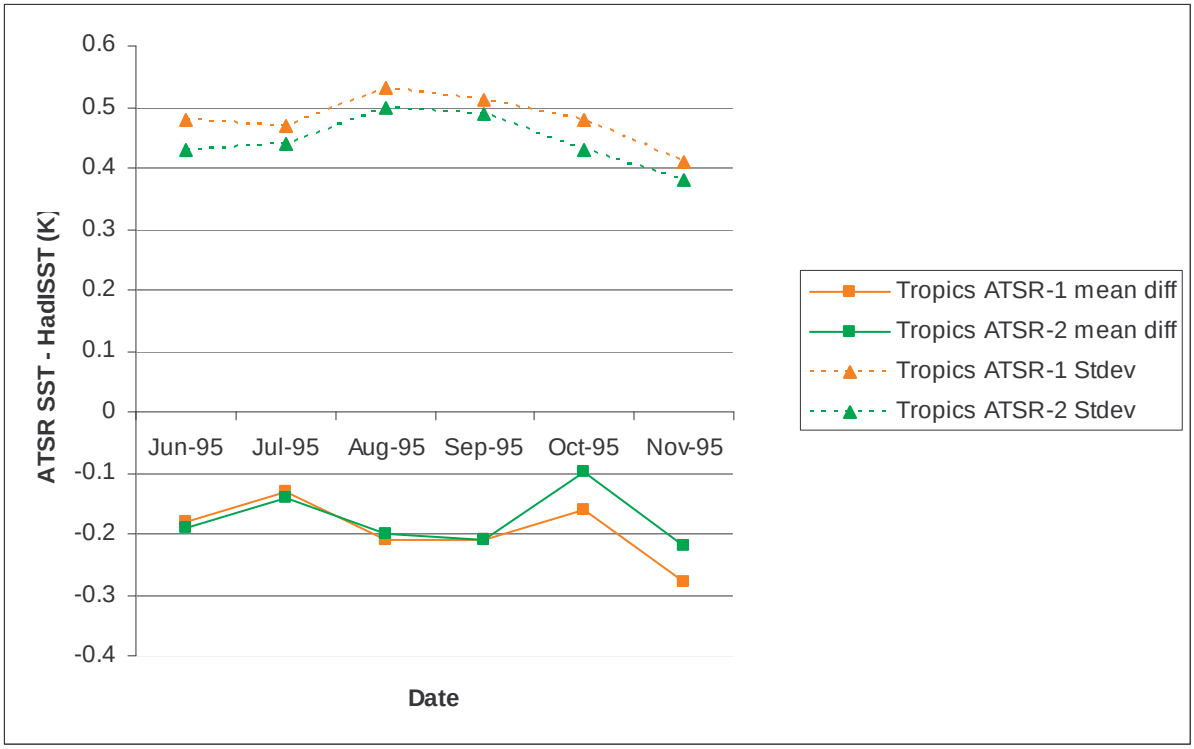
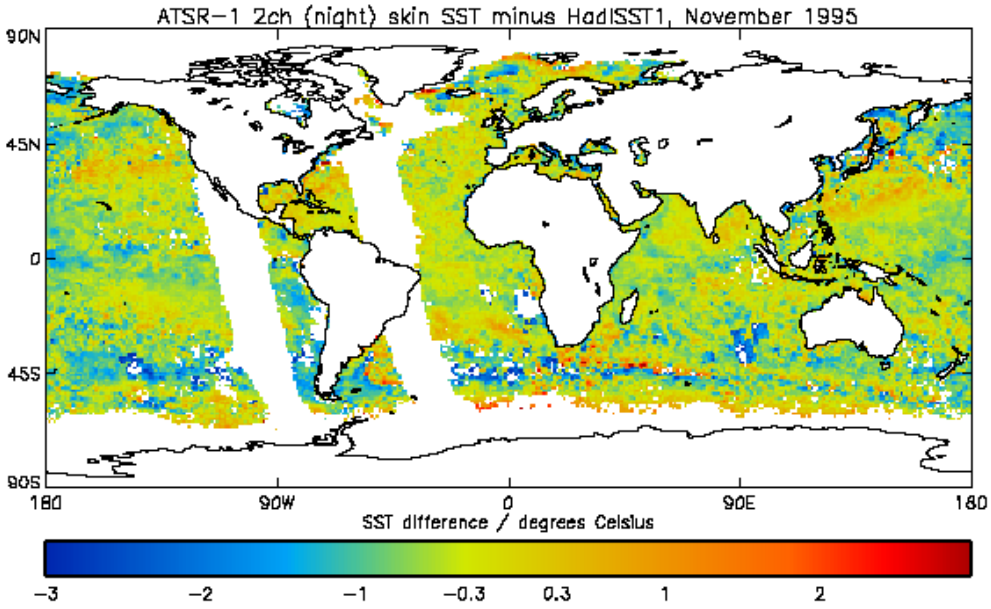



Figure 13b. Tropical (20°S to 20°N) monthly means of ATSR-1 and ATSR-2 bulk SSTs (night) minus HadISST from June 1995 to November 1995.

Figure 13a shows that throughout the 6 month ATSR-1/2 comparison window, the mean global differences between the two instruments differences with HadISST remain constant, however the standard deviations converge. The ATSR-2 standard deviations remain constant through the 6 months, however they decrease steadily throughout the period for ATSR-1 signalling an influence to the ATSR-1 retrievals differences with HadISST, which is the opposite effect to that expected if the detector temperature rise on ATSR-1 is degrading the retrievals throughout the period. However, figure 12b shows the same plot but for the tropical regions (within latitudes ±20°) where the differences are seen to diverge by October 1995, suggesting that the influence of the detector temperature rise can be seen in this plot. These low latitude regions are less susceptible to the suspected cloud contamination in the ATSR-1 retrievals at high latitudes as indicated by figure 8a to 8c.

Figures 14a and 14b below show global mean maps of ATSR-1 and ATSR-2 skin SSTs (D2 night-time) minus HadISST for August and November 1995. These figures show skin temperature minus HadISST. HadISST is more characteristic of the bulk temperature of the ocean, none-the-less the variations in patterns can still be observed. South of Africa a strip of differences where both ATSR-1 and ATSR-2 are cooler than HadISST are co-located with a line of differences where both instrument SSTs are warmer than HadISST. This characteristic is seen in both instruments for both months and is perhaps due to a strong horizontal gradient in SST where the HadISST temperatures are slightly offset. Additionally, in the North Pacific there are areas where the satellite SSTs are both cooler and warmer than HadISST, however, the 2 different instruments correlate very well in the locations that these occur.



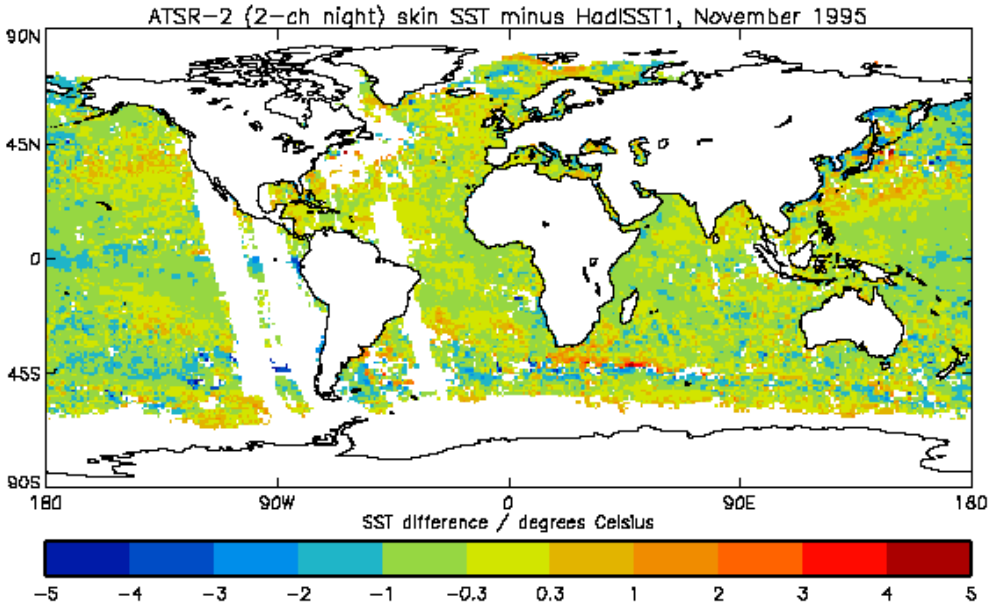




Figure 14a ATSR-1 and ATSR-2 D2 night-time skin SST minus HadISST1, for August 1995

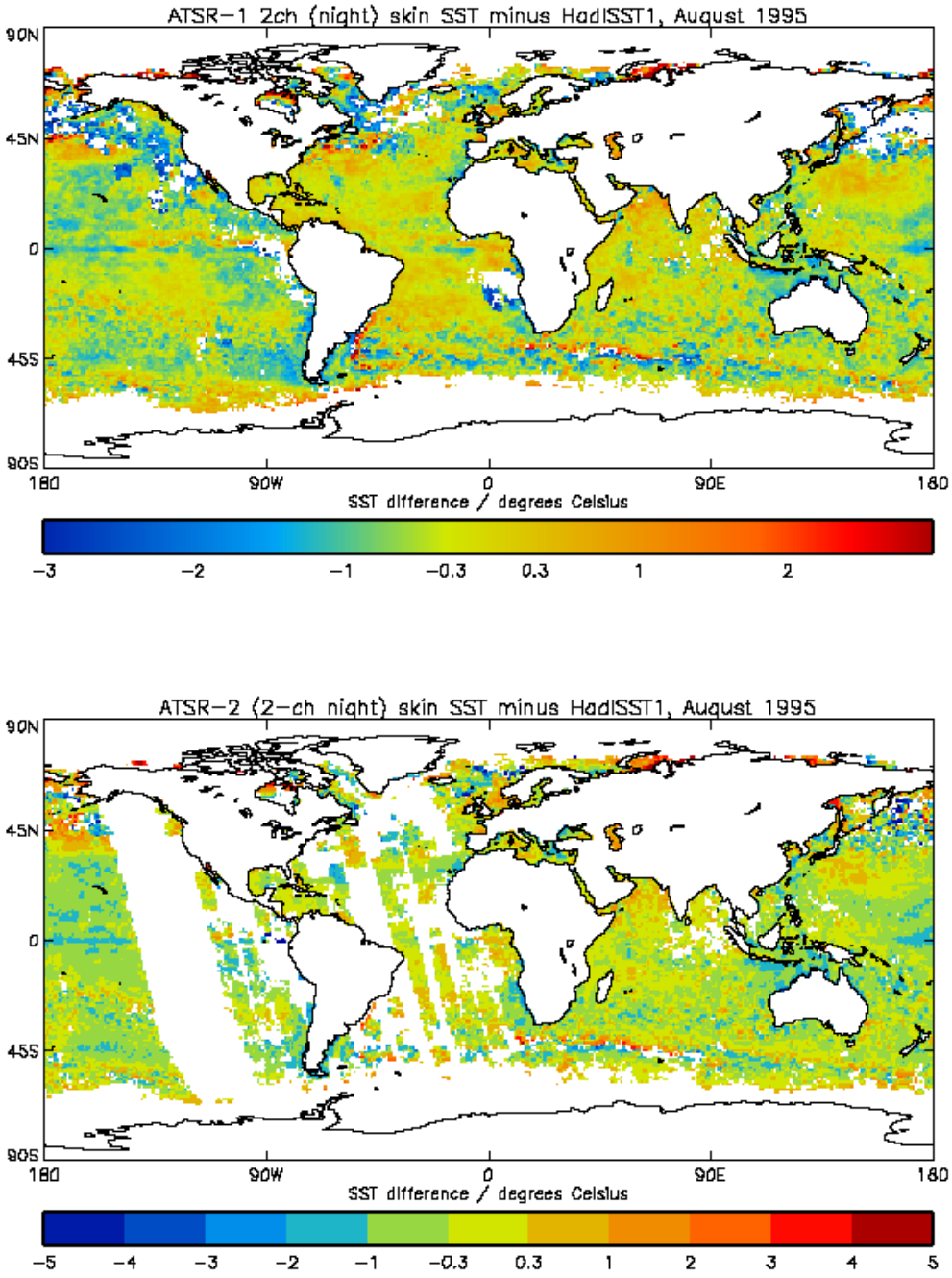



Figure 14b ATSR-1 and ATSR-2 D2 night-time skin SST minus HadISST1, for November 1995

In the November 1995 comparisons, the two satellites again correlate well with comparisons against HadISST. However, in the Southern Ocean ATSR-1 has a larger area where the ATSR-1 skin SSTs are cooler than HadISST, in some locations upto 3K cooler. There may be some residual cloud contamination occurring. Additionally as all the ATSR-1 CSCABT is flagged as 'poor', the method of using all of this data may let in some observations which would otherwise be discarded by the RAL QC.

## 3.4 Impact of ATSR-1 detector temperature rise in ATSR-1 SST retrievals

Since it is known that the rise in ATSR-1 detector temperature since 1994 will add a systematic error to the SST retrievals [Pers. Comm. A.R.Birks], ATSR-1 CSCABT data for June 1995 has been re-processed using retrieval coefficients supplied by Chris Merchant specifically for use with the detector temperature rises [7]. June 1995 was reprocessed using the 100K detector temperature coefficient file. This temperature was used after a diagram from A.R.Birks showed that this was the most relevant temperature to be used for this month. Table 7 shows the mean differences for ATSR-1 skin SST retrievals minus buoy SST for June 1995 for scenarios where the 100K detector temperature SST retrieval coefficient file is used and for where the original ATSR-1 SST retrieval coefficient file is used. Additionally, statistics from ATSR-2 comparisons with buoy SSTs for the same month are presented.

| | **ATSR1 skin–buoy SST using 100K detector temp retrieval coeff file** | | | **ATSR-1 skin – buoy SST using original SST retrieval coeff file [1]** | | | **ATSR-2 skin – buoy SST using original SST retrieval coeff file [1]** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Subset** | **mean** | **S.D.** | **num** | **mean** | **S.D.** | **num** | **mean** | **S.D.** | **num** |
| **Night** | -0.42 | 1.30 | 390 | -0.45 | 1.25 | 384 | -0.25 | 0.60 | 170 |
| **Day** | -0.22 | 0.58 | 401 | -0.23 | 0.54 | 257 | -0.37 | 0.67 | 266 |
| **All** | -0.33 | 0.90 | 686 | -0.37 | 0.88 | 641 | -0.31 | 0.61 | 435 |

Table 7 Statistics of mean D2 skin ATSR-1 and 2 differences with buoy SSTs for June 1995.

The results in table 7 indicate that use of the 100K detector temperature SST retrieval coefficient file has improved the ATSR-1 minus buoy SST mean difference by 0.03K at night, and 0.04K for both day and night. These improvements are in line with expected errors of ~0.05K for this detector temperature, these errors are known to rise to upto 0.1K when the detector temperature reaches 110K (pers.comm. A.R.Birks). For this reason it is important to consider the effect of the detector temperature and ensure use of the revised coefficients, especially at the higher detector temperature ranges towards the end of the mission, although figures 7 and 13 show better agreement towards the end of the mission for global results. There may be other factors influencing the ATSR-1 results to a greater extent than the detector temperature rise, such as problems with cloud contamination due to the lack of a 3.7μm channel.

## 3.5 Summary of overall differences for ATSR1 and ATSR2

Biases in SST retrievals are caused by two factors: retrieval errors which are state dependent and vary with atmospheric state; and also a mean global offset which varies according to whether a D2 skin retrieval or D3 skin retrieval has been performed.

In this re-processing no correction has been made for the retrieval errors, for example, no latitude-dependent offset has been applied. However, in order to compare directly the behaviour of ATSR-1 and ATSR-2 D2 retrievals we can estimate the overall global offset for each instrument. This is done using the ATSR-1 and ATSR-2 buoy-matchup datasets, correcting the "bulk" buoy SST using the Fairall model to a "skin"' buoy SST. These SSTs are then compared to the satellite skin SST (which have been re-calculated from brightness temperatures using the Merchant July 2000 coefficients [1]) and an overall bias can then be calculated for each instrument. The same offsets are applied to day-time data, as for night-time data, as only night-time matchups can be used whilst evaluating the results to avoid diurnal warming effects. The matchup criteria have been tightened to evaluate these results, where the time difference between the satellite and buoy observation now needs to be less than 1 hour. Table 8a shows the offsets for ATSR-1 and ATSR-2, calculated using the buoy-matchups datasets over the 6 month period from 1$^{st}$ June 1995 to 15$^{th}$ November 1995. The offset which can be added to skin SSTs on a routine basis to correct this bias noted in the table.

| | Mean (sat – skin buoy SST) (K) | Standard deviation (K) | Number of matchups |
|---|---|---|---|
| **ATSR-2** | | | |
| **D2 skin** | -0.05 | 0.83 | 508 |
| **D3 skin** | 0.07 | 0.75 | 509 |
| **Offset D2 night = 0.05, Offset D2 day = 0.05, Offset D3 night = -0.07** | | | |
| **ATSR-1 (original SST retrieval coeffs equivalent to those used for ATSR-2)** | | | |
| **D2 skin** | -0.10 | 0.80 | 726 |
| **Offset D2 night = 0.1, Offset D2 day = 0.1** | | | |

Table 8a. Evaluated offsets to correct mean bias for ATSR-1 and ATSR-2 D2 retrievals, using matchup data from 1st June 1995 to 15th November 1995.

Comparisons can be made with the offsets calculated for ATSR-2 using the subset of results for June-November 1995 in this section, with the results in section 2.1 which used a subset of matchups from January-August 1998. It can be seen that the D2 offset remains the same, however, the D3 offset reduces to -0.07K from -0.11K in section 2.1. By comparing the D2 offsets for ATSR-2 and ATSR-1 in table 9a, it is observed that the offset for ATSR-1 data is double that for ATSR-2 data. ATSR-1 and ATSR-2 D2 skin SSTs both have a slight cool bias when compared to skin-corrected buoy SSTs.

Table 9b shows revised offsets for ATSR-1 (evaluated only for June 1995) using the 100K detector temperature SST retrieval coefficients. So for D2 night (and day) SST processing a global offset of 0.16K should be used when using the 100K detector temperature SST retrieval coefficient file.

| **ATSR-1 (using 100K detector temperature retrieval coefficient file)** | | | |
|---|---|---|---|
| | **Mean (sat-skin buoy SST) (K)** | **Standard deviation (K)** | **Number of matchups** |
| **D2 skin** | -0.16 | 1.06 | 202 |
| **Offset D2 night = 0.16, Offset D2 day = 0.16** | | | |

Table 9b. Evaluated offsets to correct mean bias for ATSR-1 D2 retrievals (using 100K detector temperature coefficient file), using matchup data from 1st to 30th June 1995.

# 4. Conclusions and recommendations

## 4.1 ATSR-2 conclusions

The ATSR-2 skin and bulk SSTs are consistent when compared to buoy SSTs over the 5 year period (May 1995 – December 1999), with the mean ATSR-2 bulk SST (night-time) minus buoy SST difference being 0.06K and the mean ATSR-2 skin SST (night-time) minus buoy SST difference being 0.03K. These differences are very small and illustrate the ATSR-2 SST retrievals to be of high quality over the 5 year period.

## 4.2 Conclusions from ATSR-1/2 comparison

Global mean statistics of ATSR-1 compared to ATSR-2 have shown that ATSR-1 skin SST retrievals are cooler than ATSR-2 by upto 0.5K. However, within latitudes ±40° this difference decreases to 0.14K. There is possible cloud contamination at higher latitudes in the ATSR-1 data leading to this difference. Comparisons of ATSR-1 and ATSR-2 bulk SSTs against buoy SSTs for the same 6 month period in 1995 have shown there is a small difference between the 2 instrument differences with buoys of 0.03K (ATSR-1 being closer to the buoy SST than ATSR2). There is a lack of matchups at high-latitudes, thus the cases of possible cloud contamination are not included in the analysis.

There is a 0.1K difference between the mean differences of ATSR-1 and ATSR-2 bulk SSTs minus HadISST, where ATSR-1 is cooler by 0.1K compared to ATSR-2.

## 4.3 ATSR-2 processing recommendations

Processing of ATSR-2 CSCABT data from June 1995 to December 2000 is due to be finished by February 2004. It is recommended to use the global offsets derived in Table 9a (-0.05K for D2 retrievals, and -0.11K for D3 retrievals).

The record has been re-processed without a latitude dependent correction added. Users could add this if required, although new global offsets should be derived.

## 4.4 ATSR-1 processing recommendations

It is advised by RAL and Edinburgh University that from November 1994, ATSR-1 processing should utilise the revised ATSR-1 detector temperature SST retrieval coefficients [7] in order to avoid likely systematic errors of upto 0.1K, and that previous to 1994, the original aerosol-robust coefficients should be used [1]. This is supported by the improvement of buoy SST results in section 3.4, however not conclusively by figures 7 and 13. Figure 13a shows the standard deviations of global ATSR-1 and ATSR-2 differences with HadISST converging over the 6 month comparison period (so not supporting the greater influence of the detector temperature rise over the 6 month period). However figure 13b shows similar plots for the Tropics where the difference between the standard deviation of the ATSR-1 and ATSR-2 differences with HadISST remains constant, but the means diverge suggesting that the influence of the detector temperature rise is only seen at lower latitudes where there is less possible cloud contamination is occurring in the ATSR-1 retrievals (from figure 9a to 9c). Additionally, figure 6 shows the retrievals from the 2 instruments to be consistent at lower latitudes (±40º) and the differences between the ATSR-1 and ATSR-2 mean SSTs only diverge when the higher latitudes are included. Ideally more analysis should be done on this problem before reprocessing of the ATSR-1 dataset.

Although mean global offsets have been derived for ATSR-1 using the revised detector temperature files using one month (June 1995) of ATSR-1 SSTs matched with buoy SSTs, ideally these offsets should be calculated on a month by month basis from November 1994 onwards. Although ideally the calibration should be done correctly so that it is unnecessary to change the biases. Previous to November 1994 before the detector temperature started to rise, a six month period of matchup data should be analysed to calculate the offsets.

Significant evidence has been found of possible cloud contamination in the ATSR-1 SST retrievals, especially at high latitudes and to the western side of continents, due to the unavailability of the 3.7μm channel being unavailable for use in the cloud detection process. This should be monitored carefully, and perhaps only data with in the ±40º latitude band should be used with confidence.

## Acknowledgments

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